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Simulation of Ohio River Hydrodynamics to Support Emergency Maintenance Operations on Lock and Dam 52

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PURPOSE: This Coastal and Hydraulics Laboratory Technical Note (CHETN) describes the results of an engineering assessment conducted with a numerical model for a section of Lock and Dam 52 on the Ohio River. The assessment includes an evaluation of the downstream impact of four deflector designs on flow velocities.

BACKGROUND: Lock and Dam 52 is located on the Ohio River approximately 1.5 miles below Brookport, IL. The dam is approximately 2,998 ft in length, with approximately 791 ft of weir consisting of wicket gates for controlling water surface elevations (Figure 1).



Figure 1. Lock and Dam 52 on the Ohio River.

Periodically, the wicket gates are in need of repair. Typically, the gates are repaired during flows when all the gates are in the down position. Flow velocities just upstream of the gate locations can be as high as 6 to 8 fps during higher flows. The Louisville District of the Corps of Engineers estimates that flow velocities need to be 1.5 fps or less for divers to safely repair the wickets.

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To provide a safe working environment for the repair operation, flow velocities must be reduced by deflecting incoming flow around the work area. A temporary flow deflector structure was proposed by the Louisville District consisting of placement of large sandbags upstream of the area of operation. The sand bags, when filled, are approximately 4 ft wide, 4 ft deep, and 8 ft long. Approximately 100 sandbags were ordered to build the structure.

STUDY APPROACH: The Louisville District contracted with the Coastal and Hydraulics Laboratory (CHL) of the Engineering Research and Development Center (ERDC) to evaluate the impact of a number of deflector designs on flow velocities in the vicinity of the proposed work area. The District provided a high-resolution bathymetry survey of a section of the Ohio River and associated Lock and Dam 52 weirs (Figure 2). The limits of the model were built to the extents of the bathymetry for three reasons: (1) this was the only data available; (2) the urgency of the project limited the time available for the study; and (3) ERDC-CHL believed these limits could still provide useful results to aid the District. These data were used to create a numerical mesh for the two-dimensional (2D) Adaptive Hydraulics model (AdH) developed by ERDC-CHL (Berger et al. 2013). The model mesh consisted of 9,000 computational nodes and 18,000 elements. The work area for the divers was a region 16 ft × 26 ft, which contained the four wicket gates in need of repair. This is shown as the red box in Figure 3. The upstream end of the red box is considered the workface, which is front of the wickets where they are attached dam. The acceptable range of deflector standoff (distance from the workface) ranged from 3 ft to 64 ft. The reason for these limits was mainly the effectiveness of slowing velocities in the work area. Anything closer than 3 ft could block the ability to detach and attach the wickets, and anything farther than 64 ft allowed the blocked flow to realign before getting to the workface. However, a minimum standoff of 10 ft was assumed because of the uncertainty of sandbag placement in currents approaching 6 fps.



Figure 2. AdH Model Domain on Lock and Dam 52.

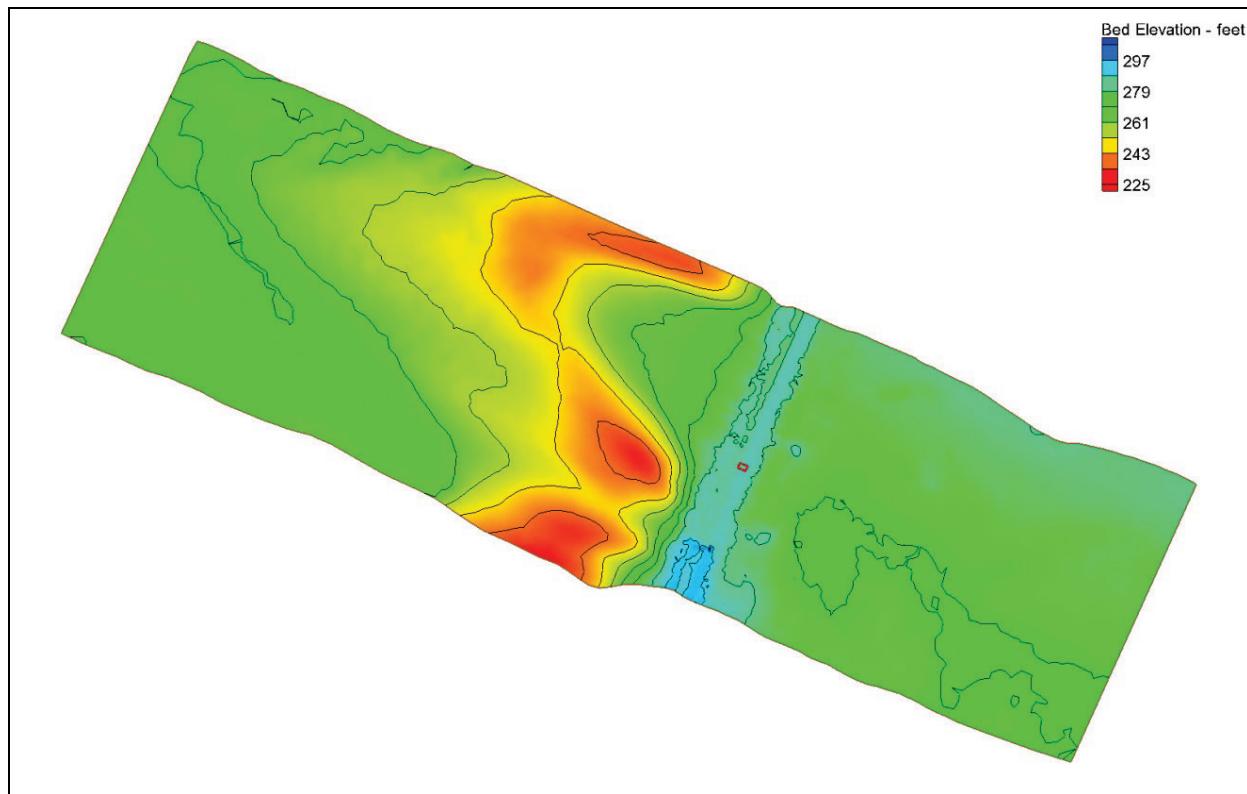


Figure 3. Existing condition model bathymetry (work area is red rectangle).

Deflector Design Criteria. The design criteria provided by the Louisville District for the deflector were as follows:

- maximum flow velocity at the workface of approximately 1.5 fps
- standoff distance of 10–64 ft
- construction requirement of approximately 100 sandbags
- effective deflection width of 16 ft or greater
- relatively simple design that can be constructed in the field.

Based on these criteria, ERDC developed three designs to evaluate in the model: a linear, a V-shaped, and a wing deflector design. However, the Louisville District could not wait for the sand bags to be delivered, so it designed and implemented a frame structure that was supported by a series of raised wicket gates on each side of the work area, which deflected flow at the sill. This design was evaluated with the AdH model, and its results are included in this technical note.

METHODOLOGY: Model simulations were conducted to evaluate the standoff distance, deflector width, and height requirement for producing the reduced flow field in the work area. Each design was evaluated at standoff distances of 10, 20, and 30 ft, with deflector crest elevations simulated at 292, 294, 296, and 298 ft NAVD 88. This represents a respective submergence of the deflector of approximately 4–10 ft. The width was also varied to obtain optimum coverage of the workface. The Louisville District provided measured field data for setting up each model simulation (river stage and measured velocities on the upstream side of the dam). There was no gage downstream for water surface elevation, so an initial tail water

elevation was set in the existing condition model that correlated to the measured upstream stage using the knowledge and experience of the lock operator. The discharge was then varied until the computed velocity matched the target velocity provided from the District field data. All simulations used these steady-state hydraulic conditions.

The existing condition (no deflectors) was initially simulated. The existing condition bathymetry is presented in Figure 3, with velocity direction and magnitude presented in Figure 4.

Twelve simulations were conducted for each ERDC deflector design (36 total). The following sections show the results of each deflector along with simulation results for the District frame deflector design.

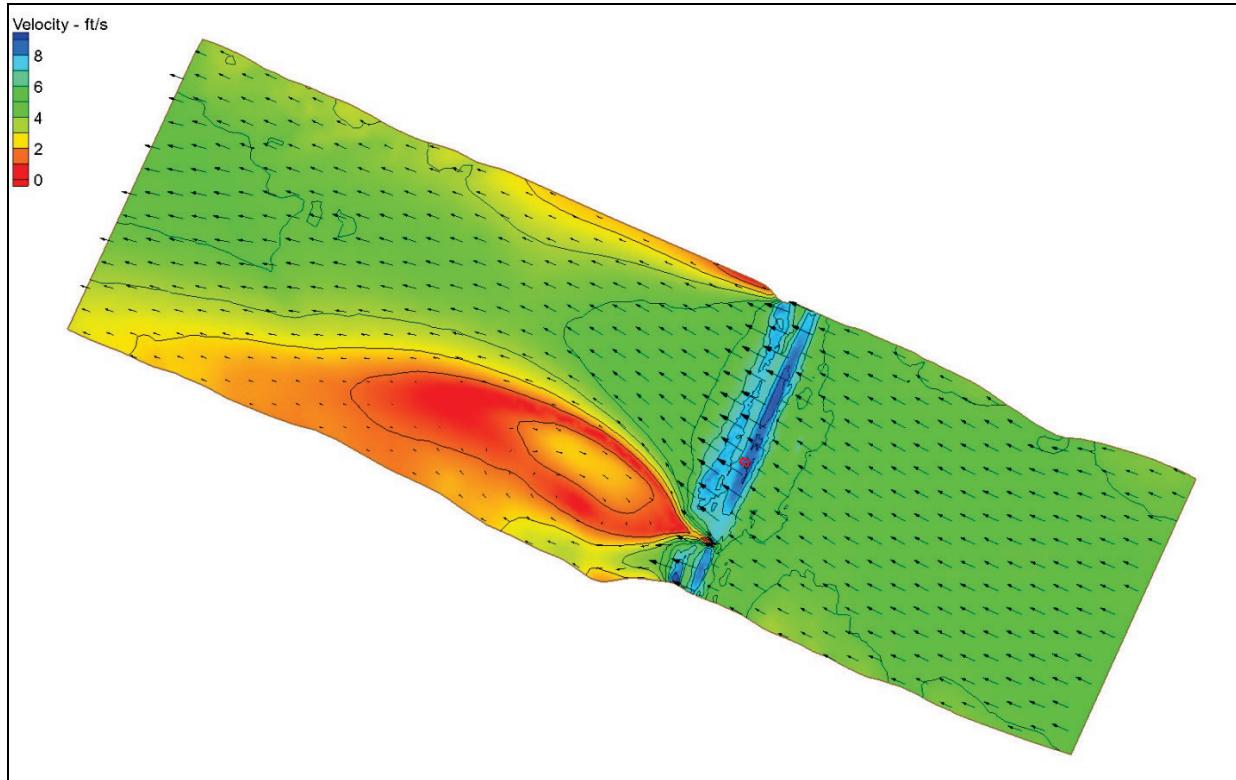


Figure 4. Existing condition—velocity magnitude and direction (feet per second).

MODEL SIMULATIONS AND RESULTS:

Linear Deflector. The linear deflector design is shown in Figure 5 along with the 16 ft × 26 ft work area (black rectangle). The thickness of the deflector had a minimal impact on design performance. The simulations indicate an optimum design of 20 ft standoff, 40 ft width, and 294 ft crest elevation, so this was run on all alternatives. The deflector was positioned in the model such that flow direction was normal to the upstream face. Figure 6 shows the velocity field around the deflector (magnitude and direction), with Figure 7 depicting the downstream flow field. Anything above 5 fps is represented by the color grey while the other areas with velocities between 0 and 5 fps are shown with blue being the fastest and red being the slowest. A complex flow field develops below the structure in which a large eddy forms directly behind the structure.

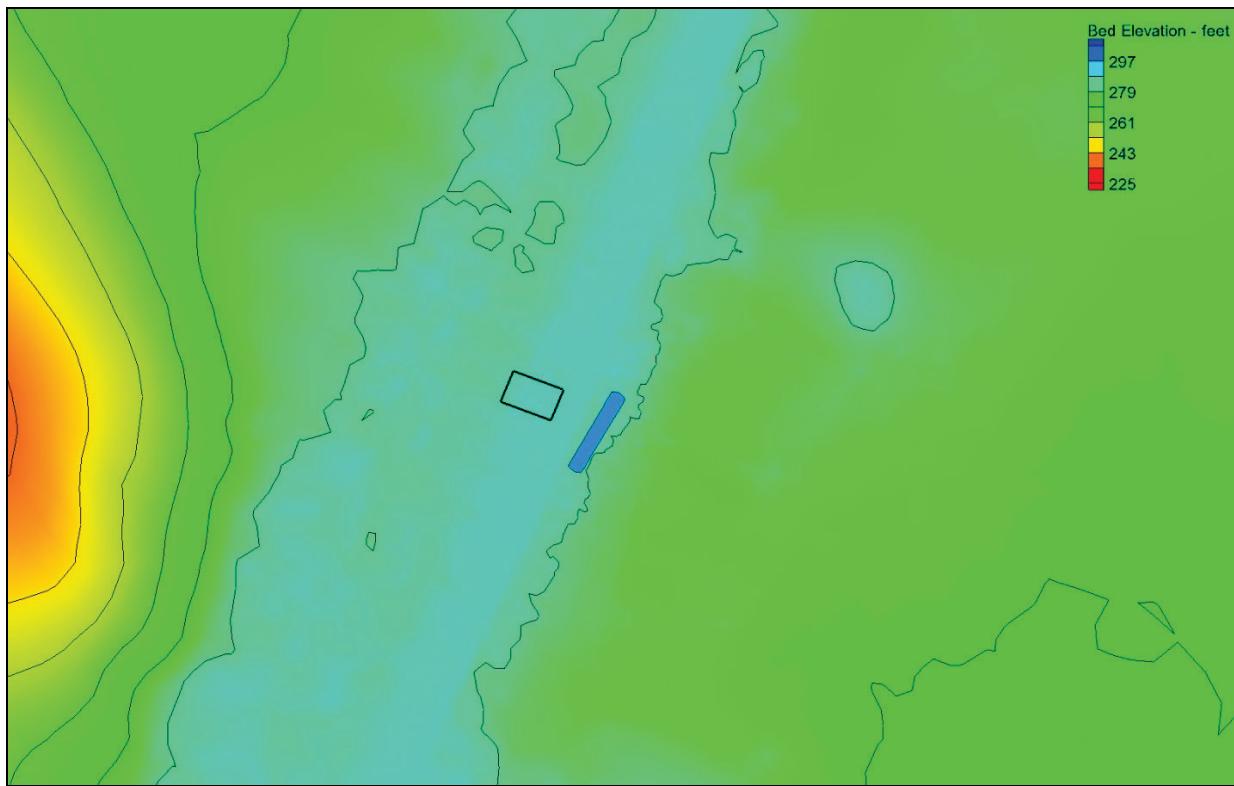


Figure 5. Linear deflector design with rectangular work area.

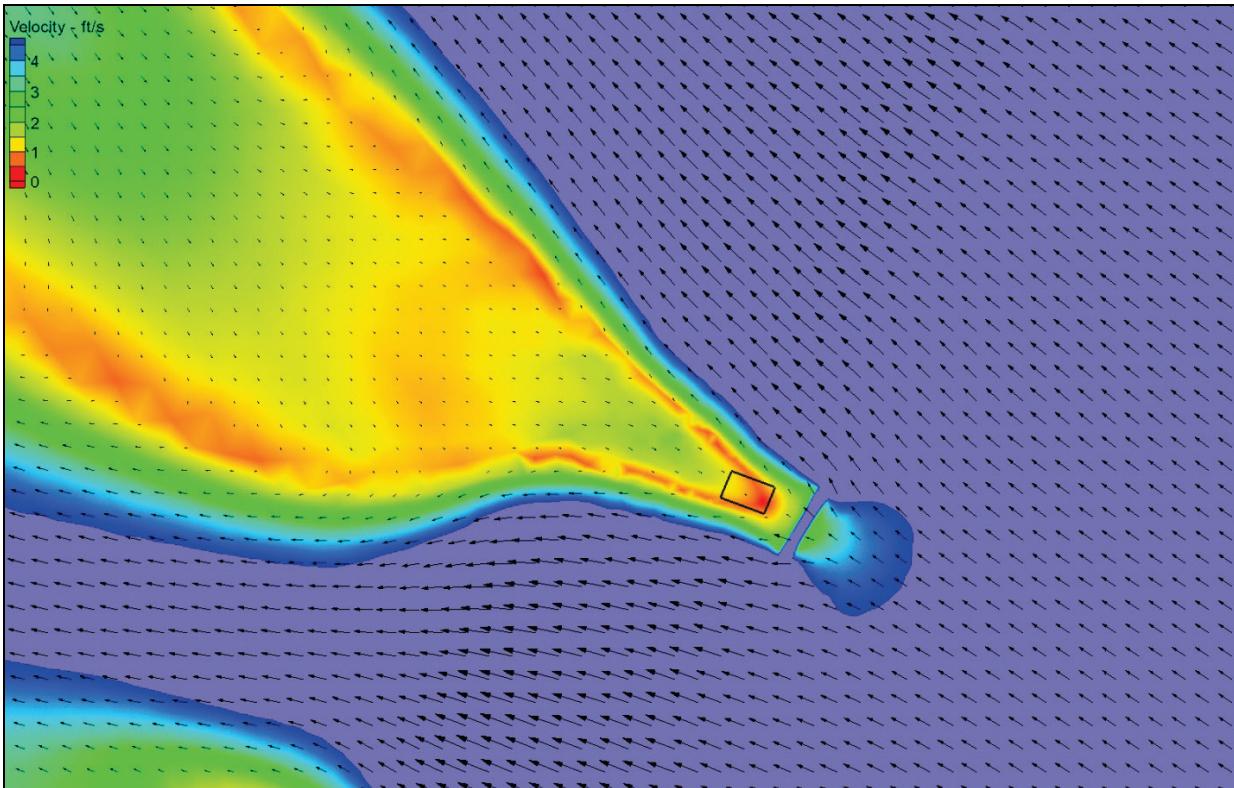


Figure 6. Results from linear deflector simulation—velocity magnitude and direction (feet per second).

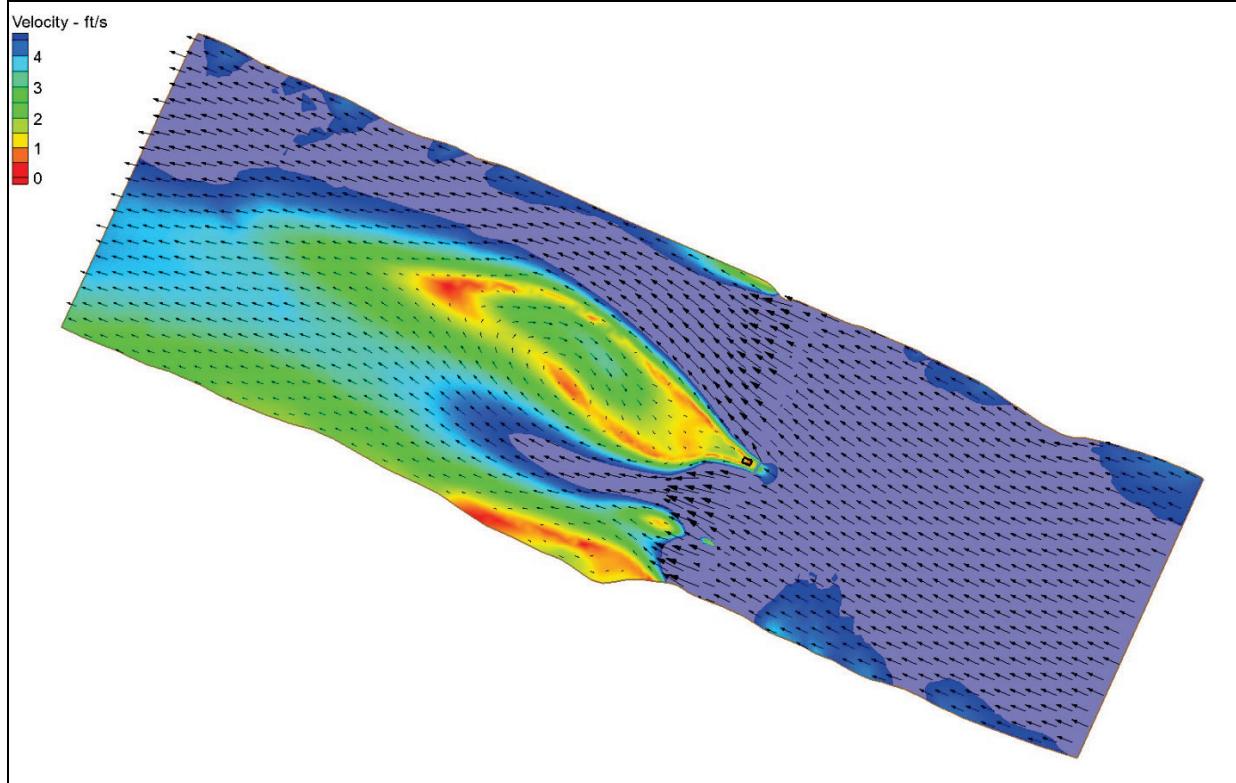


Figure 7. Downstream recirculation patterns below linear deflector.

Increased flow velocity over and around the deflector results in a lower water surface elevation; thus, the upstream-directed component of the eddy circulation moves into the work area. The location where the flow over the deflector meets the upstream circulation produces the most significant reduction of flow. For this design, the velocities along the workforce were reduced from approximately 6 fps to approximately 0.6 fps, with velocities in the work area below 1 fps.

V-Shaped Deflector. The V-shaped deflector design is shown in Figure 8. The same optimum design criteria developed for the linear design were applied to the V-shaped design. The 20 ft standoff was from the workforce to the apex of the V, with the 40 ft width referring to the maximum distance between the ends of the V. Figure 9 shows the flow pattern around and downstream of the deflector. The same type of downstream recirculation pattern develops much like for the linear deflector design right behind the structure. However, the V-shaped design is not as efficient in blocking flow; thus, higher velocities occur at the workforce (1.2 fps or greater).

Wing-Shaped Deflector. The wing-shaped deflector combines both the linear and V shape. Figure 10 shows the wing shape. It has a 10 ft-center, straight section with angled wings off of both sides, for a total span of 40 ft. Figure 11 shows the flow patterns around and downstream of the deflector. Velocities at the workforce average approximately 0.7 fps, with flow velocities less than 1.5 fps within the work area.

Frame Deflector. The District-designed frame deflector consisted of a number of raised wicket gates along with a frame inserted into the opening where the four wicket gates were being repaired. The frame design was implemented at the sill, with a top elevation of 302 ft NAVD 88.

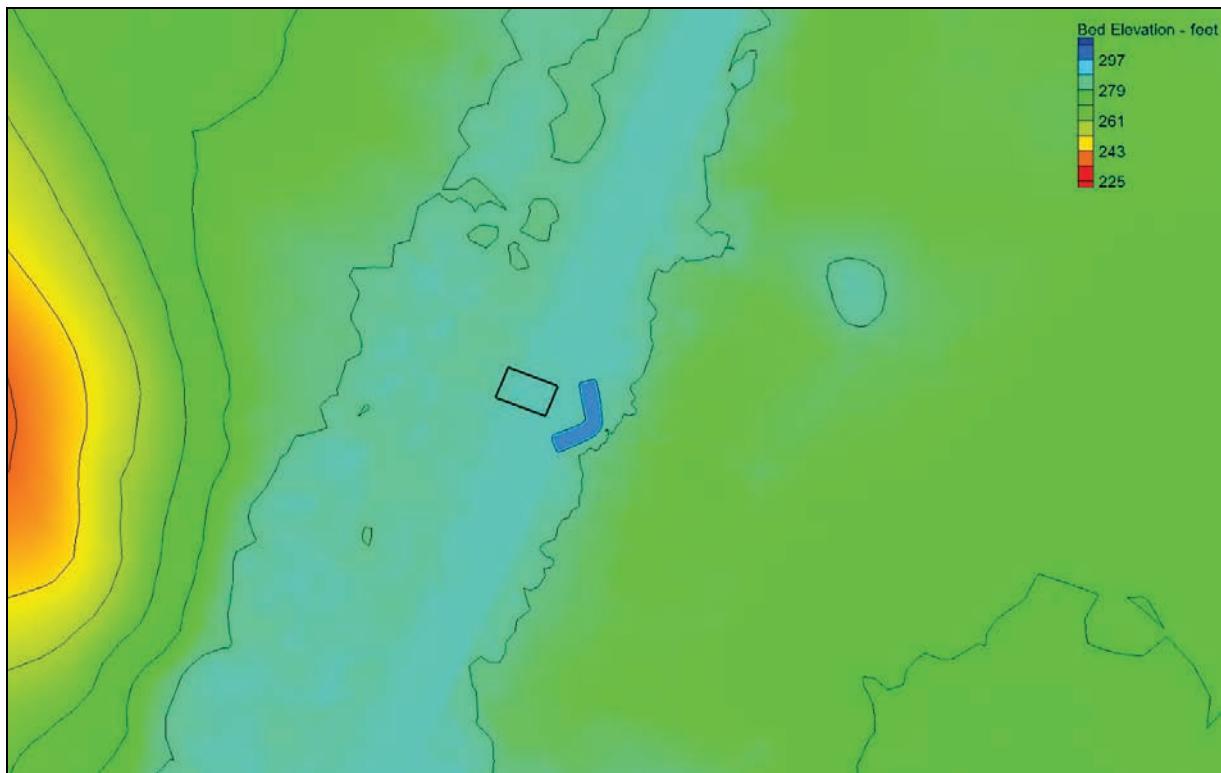


Figure 8. V-shaped deflector design with rectangular work area.

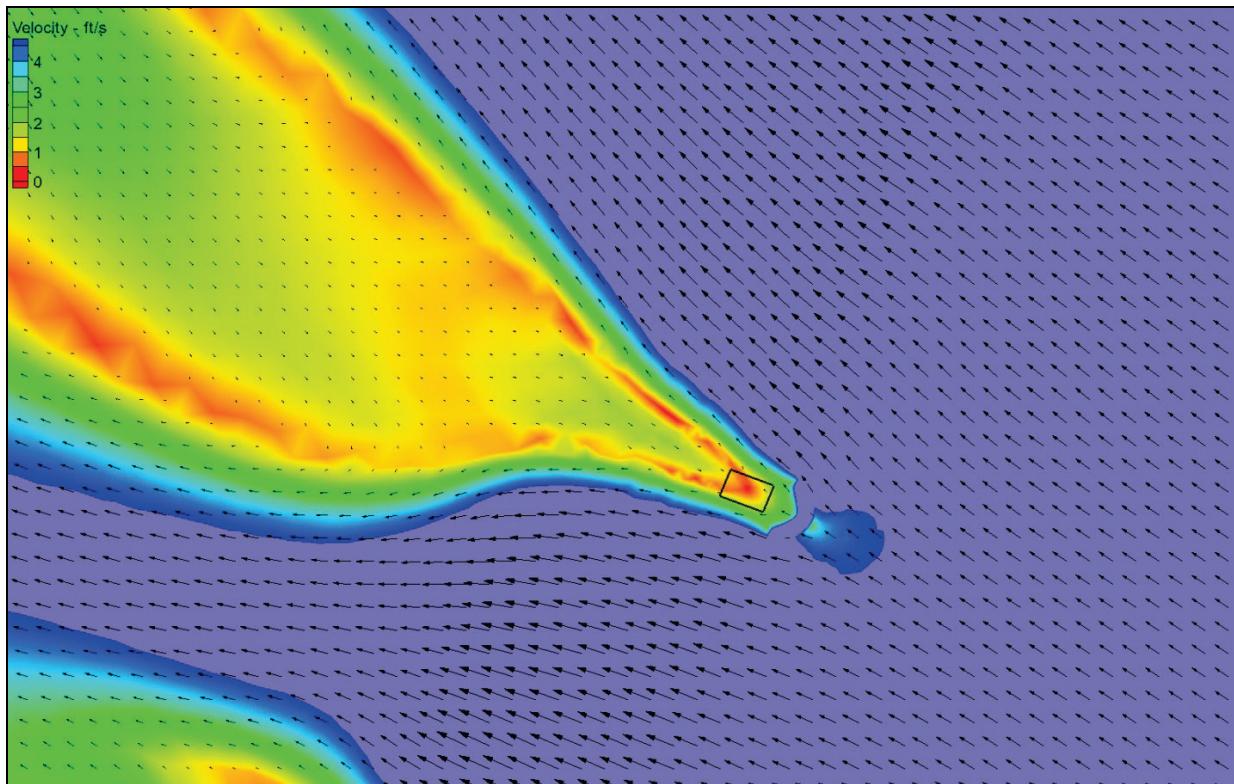


Figure 9. Result from V-shaped deflector simulation—velocity magnitude and direction (feet per second).

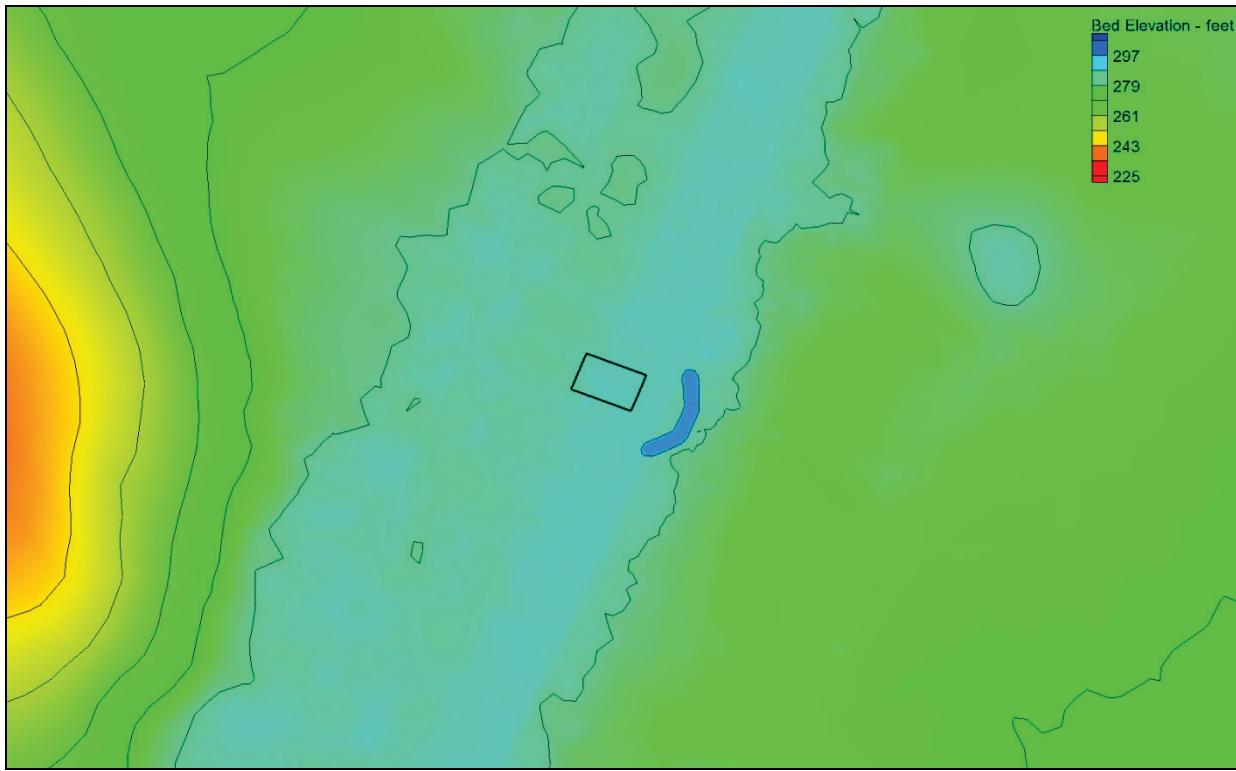


Figure 10. Wing-shaped deflector design with rectangular work area.

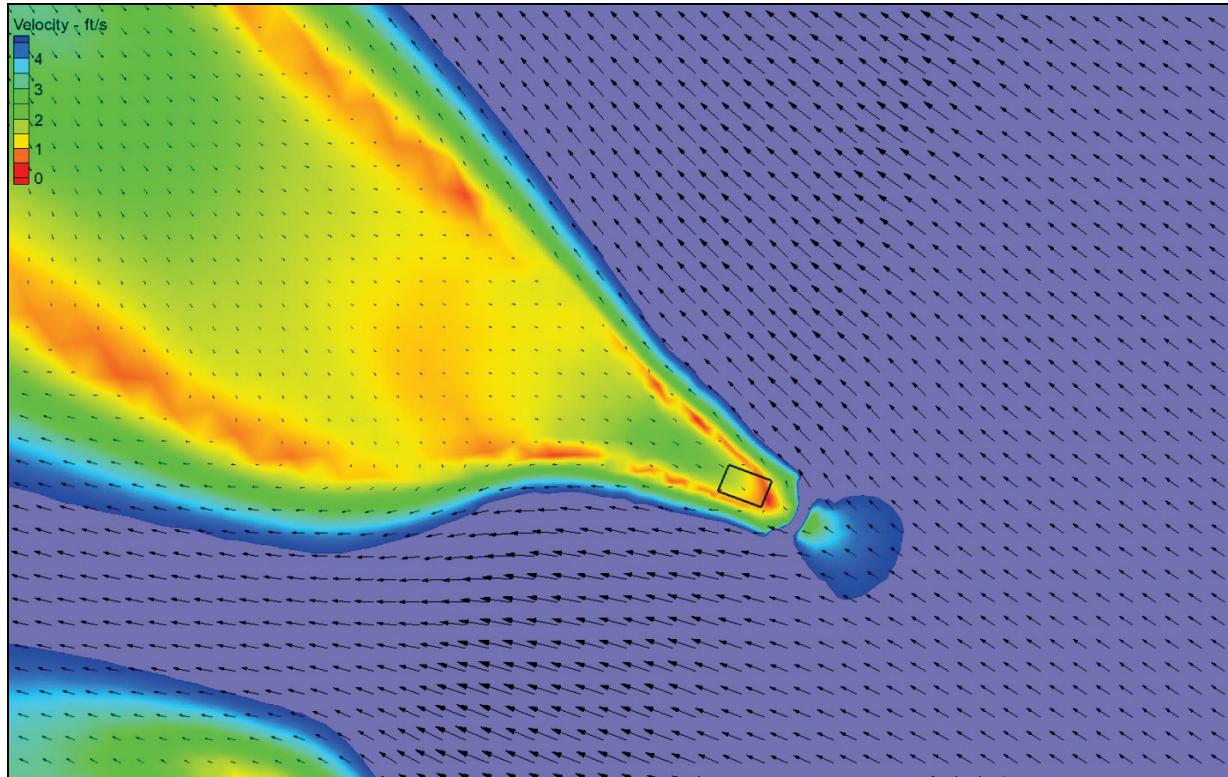


Figure 11. Results from wing-shaped deflector simulation—velocity magnitude and direction (feet per second).

Figure 12 shows the frame design in reference to the work area. Simulation results indicate a significant reduction in velocity, with an average velocity at the workface of 0.2 fps. Figure 13 shows the flow pattern around and downstream of the deflector.

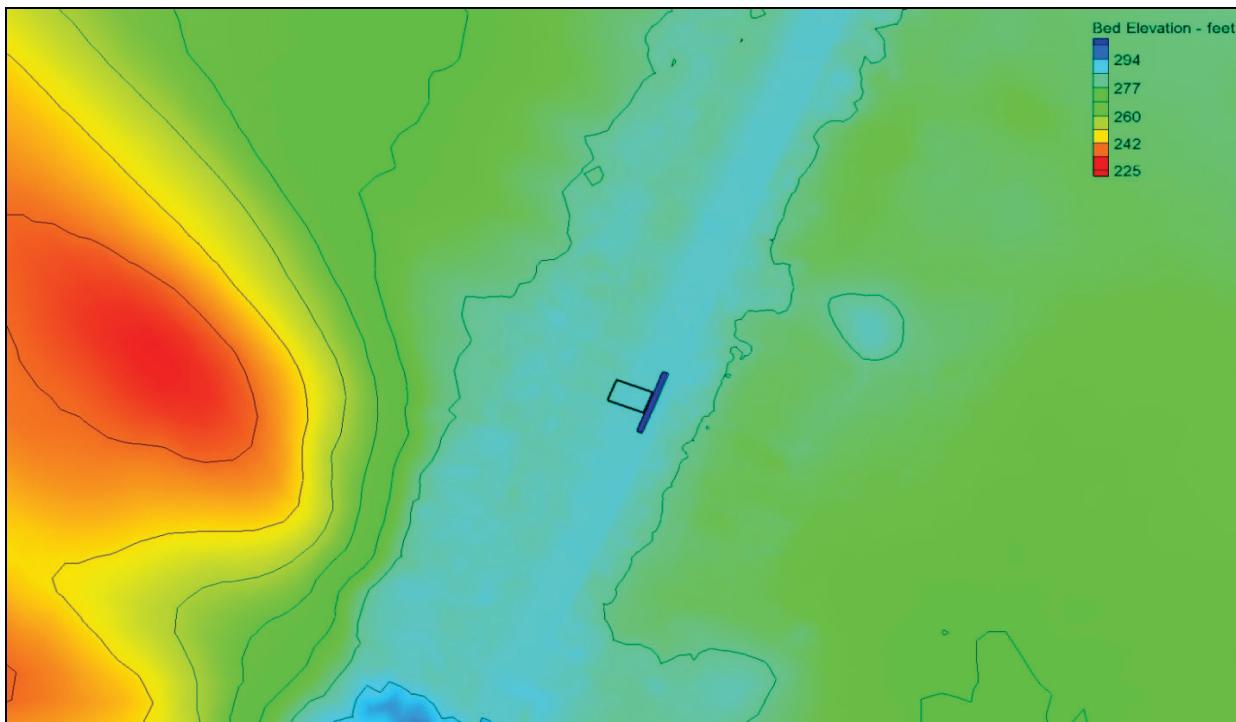


Figure 12. Frame deflector design with rectangular work area.

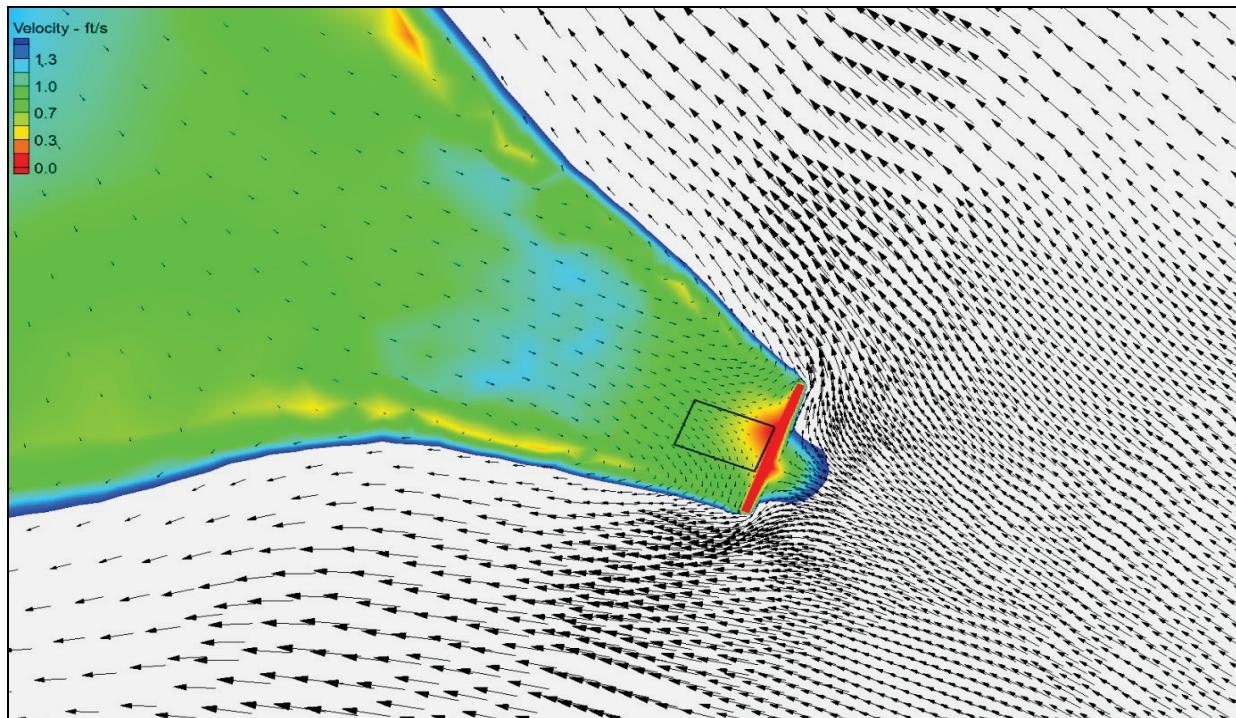


Figure 13. Results from frame deflector simulation—velocity magnitude and direction (feet per second).

SUMMARY: Of the three ERDC deflector designs, the 40 ft linear deflector with a crest elevation of 294 ft (approximately 8 ft depth of submergence) provided the minimum velocity over the workface and work area. Although all of the ERDC designs met the criteria of velocities less than or equal to 1.5 fps at the workface, the linear deflector is the easiest design to implement and can most likely be constructed with 100 sand bags or fewer.

The frame deflector designed by the District was the most effective in reducing velocity. The design was not submerged and thus deflected the maximum amount of flow around the work area. The design was successfully implemented in the field during repair operations.

Table 1 lists the velocity range across the workface for each design.

Table 1. Workface velocities for the deflector designs.			
Deflector Design	Minimum Velocity-fps	Maximum Velocity-fps	Average Velocity-fps
Linear	0.3	1.0	0.6
Wing	0.2	1.2	0.7
V-shape	1.2	1.6	1.4
Frame	0.02	0.35	0.2

In general, the greater the standoff distance from the workface to the deflector, the greater the deflector height required to reduce velocities at the workface. However, deflector crest elevations greater than 294 ft produce higher velocities over the deflector and thus will potentially increase velocities at the workface until the deflector is no longer submerged. The frame deflector was unsubmerged and thus was the most effective.

Note that using the 2D depth-averaged shallow water module of AdH comes with a set of assumptions. One of the main assumptions is that vertical acceleration is negligible. As the water passes over the sandbags in this study, it was assumed the vertical eddies are negligible/insignificant.

REFERENCES

Berger, R. C., J. N. Tate, G. L. Brown, and G. Savant. 2013. Adaptive Hydraulics: Users manual. http://chl.erdc.usace.army.mil/Media/1/2/9/9/AdH_Manual_4.3.pdf or <http://adh.usace.army.mil>

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